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Assessment of Contaminant Loss and Sizing for Proposed Lower Harbor Confined Aquatic Disposal (CAD) Cell

New Bedford Harbor Superfund Site Massachusetts

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Contents

Preface

This report describes the sediment characterization, sequential batch leachate testing (SBLT), modeling and assessment of the lower New Bedford Harbor CAD cell for sizing and contaminant loss. Testing and characterization was conducted on five composite sediment samples collected from New Bedford Harbor dredge management units (DMUs) 3 to 37 and 102 to 105. The sediment specimens were sampled and composited by Jacobs Field Services. Each composite was prepared to represent one year of dredging (at a high annual funding rate). Site water was also collected by Jacobs Field Services at the location of the proposed lower harbor CAD cell. Sediment characterization was performed by GeoTesting Express, Katahdin Analytical Services, and laboratories at the U.S. Army Engineer Research and Development Center (ERDC). GeoTesting Express and ERDC Environmental Laboratory (EL) performed geotechnical analyses. Both Katahdin Analytical Services and laboratories at ERDC EL conducted chemical analysis of the sediment composites and harbor water samples. ERDC EL also conducted SBLT on the five sediment composites to determine the partitioning characteristics of PCB and copper in the sediment. The results of the consolidation testing were used to develop void ratio-effective stress relationships and void-ratio permeability relationships for consolidation analysis. The results of the SBLT were used to develop a single set of partitioning coefficients that are representative of all of the composites for PCB and copper. Consolidation, dredged material placement and contaminant fate and transport modeling for sizing and contaminant loss were performed by ERDC EL. The EPA Remedial Project Manager is Mr. Dave Dickerson of EPA Region 1. The USACE project managers were Mr. Robert Leitch and Mr. Mark J. Anderson, Jr. of the New England District.

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This study was conducted under the direct supervision of Ms. Deborah R. Felt, Acting Chief of EP-E, and under the general supervision of Dr. Richard E. Price, Chief of EPED, Dr. Beth Fleming, Director of EL, Dr. James R. Houston, Director of ERDC, and Col. Gary E. Johnston, EN, Commander of ERDC.

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Abstract

EPA Region I is evaluating the use of CAD cells as a sediment management alternative for PCB and copper contaminated sediments at the New Bedford Harbor Superfund Site (NBHSS). This report provides EPA with short- and long-term modeling results on estimated contaminant losses and physical sediment behavior during and after filling of a potential lower harbor CAD cell (LHCC). This report also provides verification of CAD cell size for containment of the contaminated sediment and capping materials.

The sizing evaluation determined the surficial footprint of the CAD cell required to contain the sediment and capping material considering the side slope requirements, depth to bedrock, the potential for bulking during dredged material placement, and the potential spreading of the dredged material from its kinetic energy during its collapse in the CAD cell following placement. The contaminant loss evaluation included both short-term losses (prior to capping) and long-term losses (following capping). Short-term losses include displacement of CAD cell water contaminated by resuspension and stripping of dredged material during placement, consolidation of the dredged material, diffusion from the exposed dredged material, diffusion of contaminants to the upper water column from the contaminated CAD cell water, and mixing of the contaminated CAD cell water with the upper water column by turbulent diffusion and thermally induced overturning. Long-term losses include diffusion and consolidation of the dredged material from the pressure load induced by the thick deposit of dredged material and capping material.

A 650 ft x 650 ft x 47 ft CAD cell is sufficiently large to contain 335,000 cubic yards of sediment and 44,000 cubic yards of capping materials plus the potential bulking during dredging and placement. About 10 ft, or 20 to 25% of bulking, is expected, but this volume of bulking will be recovered (i.e., reduced to initial volume) within the proposed three years of placement operations. An additional 11 ft of consolidation is expected after capping as predicted using the U.S. Army Corps of Engineers' (USACE) Primary Consolidation, Secondary Compression and Desiccation of Dredged Fill (PSDDF) model.

Short-term contaminant losses to the water column above the CAD cell resulting from placement operations are predicted to be about 0.08% of the total PCB mass and 0.03% of the total copper mass placed in the CAD cell. Resuspension and stripping of dredged material during placement will increase the dissolved contaminant concentrations in the CAD cell water to be approximately equal to the sediment pore water contaminant concentrations. The losses were predicted using the USACE STFATE model (Short-Term FATE of dredged material placed in open water) to predict sediment resuspension, a partitioning spreadsheet model to compute dissolved contaminant concentrations, and the USACE RECOVERY model to predict losses by diffusion.

Capping with a 3-ft sand layer is sufficient to provide long-term isolation of the contaminants in the dredged sediment from the water column. After capping, the contaminants expelled from the dredged material by consolidation would be contained in the lower foot of the cap as predicted by the USACE CAP model. Without consideration of burial, contaminant breakthrough of the cap at a concentration of 0.01% of the pore water contaminant concentration (e.g., 0.01% of 7 ppb PCB or 0.0007 ppb PCB) will take more than 1800 years as predicted by the USACE RECOVERY model. With burial promoted by the dredged material settlement, the transport of contaminants through the cap and burial material will take tens of thousands of years.

1 — Executive Summary

Objectives

There are two objectives for this CAD cell modeling study of the proposed lower New Bedford Harbor CAD cell: verification of CAD cell size for containment of the contaminated sediment and capping materials, and quantification of contaminant losses during dredged material placement, from consolidating dredged material prior to and after capping, and from long-term diffusion after consolidation becomes insignificant. Containment includes not only capture and storage of the dredged material and capping materials, but also the bulk of the stripped or resuspended materials during placement and the dynamic spreading of the dredged material from the kinetic energy of the discharge during its collapse in the CAD cell. Contaminant losses during placement includes the partitioning of contaminants to the water column from stripped or resuspended dredged material during placement, discharge of pore water from the settled dredged material by consolidation considering the entrainment of water in the dredged material during placement, diffusion of contaminants from the dredged material and through the cap, and the exchange of water in the CAD cell with the overlying water column.

Testing

Testing and characterization was conducted on five composite samples collected from DMUs 3 to 37 and 102 to 105[1]. The sediment specimens were sampled and composited by Jacobs Field Services. Each composite was prepared to approximate one year of dredging (at a high annual rate of funding). Composite 1 was composed of DMUs 3 to 7, and DMUs 102 and 103. Composite 2 was composed of DMUs 8 to 15. Composite 3 was composed of DMUs 16 to 24 and DMUs 104 and 105. Composite 4 was composed of DMUs 25 to 33 and Composite 5 was composed of DMUs 34 to 37. Composites 4 and 5 and a portion of Composite 3 approximate the dredged material under consideration for disposal in a LHCC. Site water was also collected by Jacobs Field Services at the general location under consideration for a LHCC.

Sediment characterization was performed by GeoTesting Express, Katahdin Analytical Services, and laboratories at the U.S. Army Engineer Research and Development Center (ERDC). GeoTesting Express performed the following geotechnical analyses: Moisture Content (ASTM D 2216), Specific Gravity (ASTM D 854), Grain Size Analysis with Hydrometer (ASTM D 422), Atterberg Limits (ASTM D 4318), Flexible Wall Permeability (ASTM D 5084), and Incremental Consolidation (ASTM D 2435). ERDC analyzed the composites for moisture content (ASTM D 2216) and organic content (ASTM D 2974). Both Katahdin Analytical

[1] The original scope for this effort envisioned modeling both an upper and a lower harbor CAD cell. The scope was subsequently revised to focus on the LHCC to better support EPA's remedy decision-making process. Certain parts of this report reflect the original scope and have been retained rather than discarded to memorialize the effort undertaken to date.

Services and laboratories at ERDC conducted chemical analysis of the sediment composites and harbor water samples. ERDC laboratories also conducted Sequential Batch Leaching Testing (SBLT) (ASTM Method D-4793), on the five sediment composites to determine the partitioning characteristics of PCB and copper in the sediment. The results of the consolidation testing were used to develop void ratio-effective stress relationships and void-ratio permeability relationships for each of the five composites. The results of the SBLT were used to develop a single set of partitioning coefficients that are representative of all of the composites for PCB and copper. Results for PCB Aroclors 1242, 1254, and 1248 were reported by Katahdin Analytical Services, the ERDC laboratory, or both and the worst-case values for each Aroclor were used in the modeling. Aroclor 1248 was not included in the original plan, but was provided as part of the ERDC laboratory data reporting package and was thus included in the modeling analyses.

Modeling

Sizing and Filling

Several modeling tasks were conducted to analyze the CAD filling, sizing and contaminant losses. A cut and fill spreadsheet analysis was perform to determine the size of CAD cell needed to contain the proposed volume of dredged material and to estimate the lift thicknesses of the annual fills for consolidation analysis. A 650' x 650' surface footprint was selected with a side slope of 1V:6H for the top 7 ft of depth and 1V:3H for the remaining 47 ft of depth below the existing sediment surface.

Consolidation

The consolidation of the dredged material was analyzed using the USACE PSDDF model. The PSDDF model results showed that the CAD cell size was appropriate to contain the proposed volume of dredged material, considering the entrainment of water in the dredged material, the volume of capping material, spreading of dredged material from the placement dynamics, suspended solids retention, and consolidation prior to capping. The consolidation results were analyzed to determine the predicted pore water expulsion rates for contaminant loss predictions both prior to and after capping.

The CAD sizing analysis showed that the center of the lower harbor CAD cell would be filled with 42 ft of dredged material based on its in situ density. Analysis of potential water entrainment in the dredged material during both dredging and placement through the water column yielded an estimate of bulking or entrainment that would result in placement of 52 ft of dredged material and 3 ft of capping material, a total of 55 ft of material in our cell that is 47 ft deep. However, the PSDDF model predicted that in the center section of the CAD cell, 10.3 ft of pore water would be expelled from the placed dredged material prior to capping, primarily from the 10 ft of water that was predicted to be entrained during dredging and placement through the water column (mostly at depth from the first lift placed). Therefore, the depth of fill immediately after capping is 44.7 ft, providing a freeboard of 2.3 ft. After capping, an additional 7.2 ft of pore water is predicted to be expelled in the first 10 years, 9.4 ft of pore water in the first 20 years and 10.9 ft of pore water in the first 40 years. At 40 years, the dredged material is predicted to be 94% consolidated. Based on the PSDDF model results, much of the contaminant losses would be expected to occur during placement and prior to capping.

Placement

The open water placement of dredged material in the lower harbor CAD cell was modeled using the STFATE model to predict the entrainment of water in the deposited dredged material, the mass of dredged material suspended in the water column, the suspended solids concentration in the water column, the settling time, and the vertical and lateral distribution of suspended solids following a barge discharge of dredged material. STFATE model runs were conducted on 500-cubic yard barge discharges at the beginning and end of each dredging season to simulate the range of placement impacts for each dredging season and to estimate annual contaminant losses during placement. Losses between the beginning and end runs were assumed to exhibit a linear response based on past experience with the model.

The STFATE model results show that about 3 to 4% of the fine-grained fraction of the dredged material remains in suspension about 3 to 4 hours after the barge discharge and disperses in the CAD cell water below the loaded draft depth of the barge, resulting in average TSS concentrations ranging from about 20 mg/L for the first season to 150 mg/L for the third season. The upper 10 ft of the CAD cell water, which is potentially exchangeable with the overlying water column based on higher resolution hydrodynamic modeling of the CAD cell and its surrounding area, is predicted to have average TSS concentrations of about 5 mg/L during the first dredging season, 15 mg/L during the second dredging season and 100 mg/L during the third season, In a shallow saline environment such as New Bedford Harbor and the CAD cell, the TSS concentration will typically decrease to 50 mg/L within a day and to 10 mg/L within a week (NOTE: see results of field plume surveys in Section 5).

The discharge plume collapse dynamics were modeled using the USACE SURGE model to examine whether the momentum of the discharged material was sufficient to cause the dredged material to run up the side slope and out of the CAD cell. All discharges are assumed to be within the area of the level bottom, a 326-ft square, and no closer than 160 ft horizontally from the lip of the CAD cell. The dynamics were examined for all three sediment composites across the range of water depths that would exist during their placement. In all cases the discharged material is not predicted to run up the slope above a depth of about 11 ft below the lip or about 55 ft horizontally from the lip. Therefore, the CAD cell is expected to be capable of confining the dredged material during placement.

Short-Term Partitioning and Contaminant Loss

The contaminants associated with the TSS will partition with the CAD cell water. It is unlikely that the partitioning reaches equilibrium before the particles interact with particles from subsequent discharges, flocculate and settle. The kinetics of PCB desorption in a stagnant water column is sufficiently slow that it may take weeks to reach equilibrium; however, 10 to 20% of the PCB may desorb in the first day. The partitioning of contaminants to the CAD cell water over the large number of discharges in a dredging season is predicted to be sufficient to achieve a contaminant concentration in the CAD cell water approximately equal to the pore water concentration of the sediment or dredged material.

The dissolved contaminants and particulate-associated contaminants in the upper portion of the CAD cell will be lost as the CAD cell water is displaced by subsequent barge discharges. The displacement volumes are likely to be about 10 to 20% greater than the volume of sediment being dredged due to entrained water in the mechanical dredge/excavator bucket. This would amount to about 50,000 cubic yards in Year 1, 180,000 cubic yards in Year 2, and 150,000 cubic yards in Year 3. An additional 25,000 cubic yards of CAD cell water will be displaced in Year 3 by cap placement.

Hydrodynamics modeling yielded only low velocities in the water column above the CAD cell, typically less than 0.3 fps. The velocity is sufficiently great to rapidly exchange the water above the CAD cell, typically in one to 3 hours. The velocity is sufficiently low to limit any mixing in the CAD cell water, mostly in the top few feet. However, higher resolution hydrodynamic modeling of the CAD cell environ performed using the 3-D Environmental Fluid Dynamic Code (EFDC) model set up for NBHSS sediment transport modeling showed the potential to set up a slow vertical eddy in the CAD cell that could provide slow mixing to a depth of 10 feet below the lip of the CAD cell. Therefore, contaminants in the top ten feet of the CAD cell were subjected to turbulent dispersion and exchange with the water column above the lip of the CAD cell. The 0.3 fps current speed from the hydrodynamic modeling was considerably greater than currents measured during 2009 CAD cell field monitoring inside a deployed silt curtain (Dragos 2009). On five separate monitoring events currents inside the silt curtain were less than 0.07 fps while observed currents west and east of the CAD were up to 1.0 and 0.5 fps, respectively.

The predicted losses of PCB (Aroclors 1242, 1248 and 1254) by the placement operations (resuspension and discharge) during the three years of filling the LHCC are 310 g in Year 1 (sediment composite 3), 1,050 g in Year 2 (sediment composite 4) and 1,120 g in Year 3 (sediment composite 5), about 0.038% of the total PCB mass removed from the associated dredging. The released PCB is about 81% Aroclor 1242 (mass loss about 0.06% of Aroclor 1242 total mass placed), 5% Aroclor 1248 (mass loss about 0.009% of Aroclor 1248 total mass placed) and 14% Aroclor 1254 (mass loss about 0.018% of Aroclor 1254 total mass placed). About 85% of the released PCB is predicted to be dissolved. The 0.038% mass loss is a weighted average based on the relative contribution of each Aroclor release (81%, 5%, and 14%) to the total release and their respective mass loss rates (0.06%, 0.01%, and 0.02%). Modeling did not include losses from the capping process, but disturbances from capping are expected to be minimal as the first layer of cap will isolate the majority of contaminated sediments at the surface of the CAD and limit further loss as capping proceeds.

The predicted losses of copper by resuspension and discharge during the three years of filling the LHCC are 1.9 kg in Year 1 (sediment composite 3), 7.5 kg in Year 2 (sediment composite 4) and 34.7 kg in Year 3 (sediment composite 5), about 0.020% of the total mass of copper removed from the associated dredging. About 50% of the released copper is predicted to be dissolved.

Contaminant losses from the CAD cell after placement of the annual lift is driven by turbulent diffusion from the CAD cell to the upper exchangeable water column. The annual loss of contaminants by turbulent diffusion from the lower water column is limited to about the top 118,000 cubic yards (10 feet) of contaminated CAD cell water after the annual placement operation ceases. The CAD cell is expected to contain about 3.3 kg of PCB and 15 kg of copper in 348,000 cubic yards of CAD cell water after Year 1, 1.0 kg of PCB and 6.8 kg of copper in 192,000 cubic yards of CAD cell water after Year 2, and 0.4 kg of PCB and 7 kg of copper in 71,000 cubic yards of CAD cell water after Year 3. Following cap placement, the contaminants in any remaining CAD cell water will be lost by turbulent diffusion.

An additional potential loss of contaminants is the displacement of CAD cell water in the fall or winter by the cold dense water diving into the CAD cell. However, due to the shallow depth of the overlying water column and the mixing that would occur, this mechanism is likely to limit the exchange to no more than 5 feet of water or 71,000 cubic yards in the CAD cell. This would limit the losses to about 20% of the contaminants in the CAD cell water between dredging seasons. Any losses between dredging seasons would be partially offset by decreasing the predicted losses during the next dredging season because the initial contaminant concentration in the CAD cell water at the start of the next dredging season would be lower.

The overall potential contaminant losses resulting from placement (including losses between seasons) are 1.9 kg PCB and 9.5 kg copper from Year 1, 1.9 kg PCB and 13.4 kg copper from Year 2, and 1.4 kg PCB and 40 kg copper from Year 3. These losses represent 0.08% of the total mass of the three PCB Aroclors modeled (0.13% of Aroclor 1242, 0.02% of Aroclor 1248 and 0.03% of Aroclor 1254), and 0.03% of the copper placed in the CAD cell.

Long-Term Contaminant Loss from Capped CAD Cell

The contaminant fate and transport from the capped CAD cell were evaluated in two parts. The first part was evaluated during the period of dredged material consolidation using the USACE CAP model, which considers pore water advection induced by consolidation. Ninety percent of the consolidation is completed only after 30 years, but meaningful contaminant transport by pore water expulsion is limited to the first two to four years. The second part was evaluated for the long term, after significant pore water advection ceases. During the long term, contaminant transport is dominated by diffusion of contaminants from the dredged material and into the cap. Long-term contaminant fate and transport from the capped CAD cell was modeled without considering contaminant degradation or transformation using the USACE RECOVERY model.

The CAP model was run on four separate sections of the CAD cell due to differences in dredged material thickness and predicted settlement. Each section represents about one quarter of the area of the CAD cell. The first section represents the center of the CAD cell and includes the entire section of the cell that has a level bottom. The next three sections are concentric bands around the center covering the sloped area of the CAD cell (see Figure 12). Each band has successively thinner dredged material thicknesses and smaller settlements. The CAP model results showed that the contaminants transported from the dredged material by pore water advection and diffusion would be contained in the lower foot of the cap, even in the center section, which had the largest settlement. The contaminant and sediment profiles from the end of the CAP model runs were used as the initial conditions for the long-term modeling using the RECOVERY model.

The RECOVERY model was used to compute contaminant concentrations in the cap as a function of time and to predict the time required for breakthrough of the contaminants.

Contaminant breakthrough as applied here is based on a limiting contaminant flux or surficial pore water concentration that might start to pose a meaningful risk to receptors; in this case, a relative flux or concentration of 0.01% of the original flux or concentration of the sediment was used to define breakthrough. The RECOVERY model showed that most mobile of the contaminants was PCB Aroclor 1242, followed by copper and PCB Aroclors 1248 and 1254. Contaminant breakthrough through the 3-foot cap by Aroclor 1242 at a concentration of 0.0006 ppb and copper at a concentration of 0.01 ppb is predicted to occur only after 1800 years and 4700 years of diffusion, respectively. The peak concentration in copper is predicted to be only 0.012% of its initial concentration (about 0.012 ppb) and occur at 6500 years. Aroclors 1248 and 1254 at concentrations of 0.000012 and 0.000077 ppb, respectively, are predicted to breakthrough the cap only after more than ten thousand years. The model shows that a stable 3-foot cap is highly effective in isolating the contaminated dredged material. Since about 11 ft of settlement is predicted for the center section of the CAD cell, there is a very large potential for up to 11 ft of burial over the life of the CAD cell. If this burial were considered in the long-term fate and transport modeling, the CAD cell would be effective for all contaminants for tens of thousands of year. In reality, the contaminant concentrations in the surficial cap will be controlled by the deposition of surrounding contaminated materials onto the cap, and not by contaminant migration by the buried dredged material.

Conclusions

1. A 650-foot square CAD cell excavated 47 ft below the existing sediment surface is sufficient in size to hold and cap the sediments proposed for a lower harbor CAD cell and to contain the lateral spread and collapse of the dredged material discharge during placement.

2. About 10 ft of water will be entrained in the dredged material during placement, but all of this water is predicted to be expelled from the consolidating dredged material during the three years of placement.

3. An additional 11 ft of settlement and pore water expulsion is predicted to occur after cap placement.

4. Dredged material resuspension will occur during placement, resulting in predicted TSS concentrations ranging from 20 to 150 mg/L and both dissolved and particulate-associated contaminant release to the water column overlying the CAD cell.

5. The resuspension predictions appear to be a reasonable and conservative representation of the behavior of actual plumes observed during similar dredged material placement in a City of New Bedford CAD cell in 2009.

6. Dissolved contaminant concentrations in the CAD cell water (but not the overlying water) during filling will become approximately equal to the sediment pore water being placed in the CAD cell.

7. About 2.4 kg of PCB are predicted to be lost during dredged material placement in the lower harbor CAD cell, 85% of which would be dissolved. About 44 kg of copper are predicted to be lost during dredged material placement, 50% of which would be dissolved. These losses represent about 0.038% of the total PCB mass and 0.020% of the total copper mass being placed into the CAD cell.

8. Hydrodynamics modeling yielded only low velocities in the water column above the CAD cell, typically less than 0.3 fps. The velocity is sufficiently great to rapidly exchange the water above the CAD cell, typically in one to 3 hours. The velocity is sufficiently low to limit any mixing in the CAD cell water, mostly in the top few feet. However, higher resolution hydrodynamic modeling of the CAD cell environ performed using the 3-D EFDC model set up for sediment transport modeling showed the potential to set up a slow vertical eddy in the CAD cell. The eddy could provide slow mixing to a depth of 10 feet below the lip of the CAD cell. Therefore, contaminants in the top ten feet of the CAD cell were subjected to turbulent diffusion and exchange with the water column above the lip of the CAD cell.

9. Additional losses due to potential turbulent diffusion and thermally induced displacement over the winter between dredging seasons could result in about 2.7 kg of additional PCB being lost from the CAD cell water prior to capping, resulting in a total loss from placement operations of 0.08% (5.2 kg) of the total PCB mass disposed in the cell. Similarly, an additional loss of about 18 kg copper could be lost by these mechanisms, resulting in a total placement loss of about 0.028% (63 kg) of the total copper mass disposed in the cell.

10. Placement losses are predicted to be one to two orders of magnitude less than typical losses from mechanical dredging operations.

11. After capping, the contaminants expelled from the dredged material by consolidation would be contained in the lower foot of the cap.

12. Without consideration of burial (i.e., the additional sediment deposition that will take place over time into the bowl-shaped CAD cell depression formed by consolidation after the cap is placed), contaminant breakthrough will take more than 1800 years. Again, breakthrough, as used here, is defined as the condition when the contaminant flux or surficial pore water concentration increases to levels of 0.01% of the original flux or sediment bed concentration before dredging and disposal. With burial promoted by the estimated ten feet of post-cap dredged material settlement, the transport of contaminants through the cap and burial material will take tens of thousands of years to achieve the breakthrough.

13. A stable 3-ft cap would be highly effective in isolating the contaminated dredged material.

14. Acceleration of the placement schedule would increase the size of the CAD cell needed to contain the 325,000 cubic yards of sediment proposed for placement in the lower harbor CAD cell while maintaining conditions to promote settling and stability. The increase in storage requirements is due to shortening the time available for consolidation. Schedule acceleration is also predicted to decrease the contaminant losses due to the reduction in the exposure of contaminated CAD cell water for losses to occur.

2 — Introduction

Background

Report Objectives

The first objective of this report is to provide EPA Region I with short- and long-term modeling results on estimated contaminant losses and physical sediment behavior during and after filling of a proposed CAD cell being considered as a sediment management alternative at the NBHSS. The second objective is to provide verification of CAD cell size for containment of the contaminated sediment and capping materials.

The quantification of contaminant losses was estimated for dredged material placement, from consolidating exposed dredged material prior to capping, and from long-term diffusion following capping after consolidation becomes insignificant. Containment includes not only capture and storage of the dredged material and capping materials, but also the bulk of the stripped or resuspended materials during placement and the dynamic spreading of the dredged material from the kinetic energy of the discharge during its collapse in the CAD cell. Contaminant losses during placement includes the partitioning of contaminants to the water column from stripped or resuspended dredged material during placement, discharge of pore water from the settled dredged material by consolidation (considering the entrainment of water in the dredged material during placement), diffusion of contaminants from the dredged material and through the cap, and the exchange of water in the CAD cell with the overlying water column.

General Setting

New Bedford Harbor, located in southeastern Massachusetts, is a relatively shallow coastal estuary (Figure 2). It is connected to Buzzards Bay to the south. The main freshwater flow enters in the north from the Acushnet River. A 9-m deep (30-ft) Federal navigation channel extends from Buzzards Bay into the harbor along with a 7.6-m deep (25-ft) anchorage and adjacent 4.6-m deep (15-ft) and 3.0-m deep (10-ft) channels, which serve the Town of Fairhaven. The harbor is home to one of the nation's largest commercial fishing fleets.

Modeling Study Background

The alternative under consideration in this report includes a CAD cell in the lower harbor (Figure 2). The CAD cell would be created by excavating into the natural glacial sediments in the bottom of the harbor in order to create storage and isolation for the contaminated sediments. CAD cells are already in use in New Bedford Harbor by the city (USEPA 2009) and have also been successfully used in New England in Boston, Providence, New London, Hyannis, and Norwalk (Fredette 2006). The exact footprint of the lower harbor CAD cell is yet to be determined, but consistent with the state's long term Dredge Material Management Plan would be located between the Rt. 6 and Rt. 195 bridges, and would be sized to dispose approximately 300,000 cy of Superfund dredged material and organic silts from excavation of the upper harbor CAD cell.

The material to be placed in the lower harbor CAD cell would be the less highly contaminated Superfund sediments primarily located in the lower harbor. Filling of the CAD cell is anticipated to extend over two to three years followed by capping to isolate the contaminants from the environment. A perimeter silt curtain is proposed for the LHCC to minimize potential contaminant loss during placement.

CAD Cell Design Used for Modeling

Since the LHCC is only in the evaluation stage (without a specific design), we developed a generic design based on review of the existing CAD cells that have been created by the City of New Bedford. The generic CAD used in the modeling had a 650' x 650' surface footprint and a maximum depth 47 feet deeper than the surrounding harbor floor. Side slopes for the first seven feet of CAD were set at 1V:6H and for the remaining 40 ft of depth we used 1V:3H. Disposal into the CAD cell was based on placement in 500 cubic yard increments from a barge with a draft of eight feet and a hopper 88 feet long. A schematic of the CAD cell scaled to these features is shown in Figure 3.

Study Approach

The study presented here was conducted in two phases. **Phase 1** involved review of existing reports and databases on site characteristics to assess data sufficiency for modeling the short- and long-term loss of contaminants. For each of the proposed models, the necessary input and boundary conditions were considered in light of the available information. Based on the review, several key data gaps were identified leading to recommendations for specific field and laboratory work. In order to fill the data gaps identified in Phase 1, a field sampling and laboratory analysis plan was developed. Sediment cores and site water were collected by Jacobs Field Services during the period of 30 March to 8 April 2009 (Jacobs 2009a). Laboratory analysis proceeded in the following weeks.

Phase 1

The NBHSS project sediment database and technical reports on New Bedford Harbor sediment characteristics, water quality, sub-surface geology, and ground water flow were reviewed to assess the existing information to determine whether any additional data needed to be collected for the planned modeling activities. These sources provided considerable information that could be directly used as part of the modeling efforts (see Phase 1 report, Appendix A). Data types that were determined to be sufficient included foundation properties, sediment copper and PCB concentrations, sediment grain size, water content, specific gravity, and Atterberg limits. Data on sediment pore water contaminant concentration and partitioning to the water column during dredging and disposal were less well understood and were therefore identified as important data gaps.

The specific recommendations identified in the Phase 1 report (Appendix A) were as follows:

Annual Dredging Sediment Composites: Seven[2] sediment composites, five in the Upper Harbor and two in the Lower Harbor, should be collected, representing the average of the sediment DMUs to be dredged in each of the years. Care should be taken to collect sufficient samples from each DMU to form each composite so that each composite is representative of the average PCB, Cu, TOC and DOC concentrations, as well as the average water content, silt and clay content, and oil and grease content of the sediment being dredged each year.

Sediment Analysis Needs for Each Composite: Each composite should be analyzed for its bulk sediment concentration of Total PCB (based on congener analysis), Aroclor 1242, Aroclor 1254, Cu, AVS, Oil and Grease, TPHs, and TOC. Additionally, the pore water of each composite should be analyzed for total and dissolved concentrations of Total PCB, Aroclor 1242, Aroclor 1254, Cu, and Organic Carbon. The pore water should also be analyzed for salinity, TDS, and TSS. Each composite should be characterized for its geotechnical properties, including water content, specific gravity, organic content, Atterberg limits, and grain size distribution.

Site Water Samples: Site water should be collected from the two proposed CAD sites for analysis and use for testing.[3]

Site Water Analysis Needs: The site water samples should be analyzed for total and dissolved concentrations of Total PCB (based on congeners), Aroclor 1242, Aroclor 1254, Cu, Oil and Grease, TPHs, and Organic Carbon. The site water should also be analyzed for salinity, TDS, and TSS.

Testing Needs:

Standard Elutriate Tests should be run on each of the seven sediment composites using the proposed CAD site water to predict short-term losses during disposal. The composites should be analyzed for elutriate total and dissolved concentrations of Total PCB (based on congeners), Aroclor 1242, Aroclor 1254, Cu, Oil and Grease, TPHs, Organic Carbon and also TSS.

Sequential Batch Leaching Tests for partitioning characteristics should be run on each of the seven sediment composites to determine partitioning characteristics for PCB (total based congeners), Aroclor 1242, and Aroclor 1254, and Cu. Four cycles should be used for PCB and seven cycles should be used for Cu. Each composite should be analyzed for leachate total and dissolved concentrations of Total PCB, Aroclor 1242, Aroclor 1254, Cu, Oil and Grease, TPHs, Organic Carbon and also TSS.

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[2] Subsequent to this early assumption of seven composites an analysis of annual dredging volumes and their estimated contaminant concentrations resulted in a decision to reduce the total number of anticipated sediment composites to five; three for the upper harbor and two for the lower harbor. This is discussed in the next section.

[3] See footnote #1: the text here reflects the original rather than the revised scope of work.

Standard Oedometer Consolidation (ASTM D2435) and Permeability Tests should be run on each of the seven sediment composites to determine consolidation properties for consolidation of the dredged material in the CAD sites and for seepage of pore water from the CAD sites.

As a result of the review and the anticipated dredging schedule which would place annual layers in the cells it was determined that data to characterize each lift in more detail would provide greater confidence in the modeling results. This resulted in a plan to collect both sediment and water chemistry data from samples composited to represent each of the proposed annual dredging cycles. The reasoning for collecting sediment chemistry data for these samples, even though sediment chemistry was determined to be adequate during the data gap review, was that understanding the relationship between observed pore water chemistry and chemical partitioning behavior relative to the original sediment matrix was critical.

<u>Phase 2</u>

Phase 2 involved modeling short- and long-term losses using the existing and/or newly collected data. This report focuses on the model results for the lower harbor CAD cell. The models are briefly described here and greater detail on their application is provided in later sections of this report. Model descriptions for STFATE, PSDDF, and RECOVERY/CAP are based on Schroeder et al. (2004).

STFATE. The short-term fate of dredged material model (STFATE) mathematically models the physical processes determining the short-term fate of dredged material disposed at open-water sites within the first few hours after disposal.

Major Capabilities:

- Estimates receiving water concentrations of suspended solids, dredged material liquid and suspended phases, and dissolved contaminants as a function of time and location.
- Estimates the percentage of suspended solids deposited on the bottom as a function of time and location and the thickness of deposition.

SURGE. The SURGE model mathematically predicts the collapse and spread of the discharge cloud after it impacts the bottom using the mass and velocity of the discharge cloud as predicted by the STFATE model. The model is used to determine whether the energy of the discharge is sufficient for material to run up the sides of the CAD cell and out of the cell.

Major Capabilities:

- Predicts the distance that the discharge material will run up the slope, considering the kinetic energy of the discharge, change in potential energy, and frictional losses.
- Predicts deposition location by size class, considering the critical shear stress of each size class and the velocity of the collapsing cloud of discharge material.

PSDDF. The consolidation, compression, and desiccation of dredged fill (PSDDF) model provides a mathematical model to estimate the storage volume occupied by a layer or layers of dredged material in a confined disposal facility (CDF) or for underwater placement as a function of time.

Major Capabilities:

- Determines the final or ultimate thickness and elevation of multiple lifts of dredged material placed at given time intervals.
- Determines the time rate of settlement for multiple lifts and therefore the surface elevation of the dredged material fill as a function of time.
- Determines the water content, void ratio, total and effective stress, and pore pressure for multiple lifts as a function of time.

RECOVERY/CAP. The contaminant release from bottom sediments model (RECOVERY/CAP**)** is a screening-level model to assess the long-term impact of contaminated bottom sediments on surface waters. The model couples contaminant interaction between the water column and the bottom sediment, as well as between the contaminated and clean bottom sediments. Processes incorporated in the model are sorption, decay, volatilization, burial, resuspension, settling, bioturbation, and pore-water diffusion.

Major Capabilities:

- Allows for a rapid analysis of recovery scenarios for contaminated sediments and cap evaluations.
- Simulates behavior of organics in a real system with a limited amount of data.
- Predicts desorption of contaminants from sediments.

3 — Data Sources, Collection, Testing and Analysis

Data Sources

The following data sources (reports and data bases) along with other technical reports and background information obtained at http://www.epa.gov/ne/nbh/techdocs.html were considered in the development of a sampling and testing plan to gather data for evaluation of the CAD cells. Reviewed reports and data bases (supplied by the New England District) include:

1. Technical Memorandum, Preliminary CAD Cell Volume Capacity Analysis. 2006. Apex Companies and Jacob Engineering Group.

2. Draft CDF C Groundwater Model Technical Memorandum. 2001. Foster Wheeler Corp.

3. 12-Volume Engineering Feasibility Study. 1988-89. Technical Report EL-88-15, Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

4. New Bedford, Sawyer Street Quarterly Groundwater Sampling, Analytical Results, March 1992 - March 2001.

5. Quarterly Sampling at Sawyer Street CDF, October 2004-October 2006. 2006. ENSR/AECOM.

6. Overview of the New Bedford Harbor Physical/Chemical Modeling Program, April 1, 1991 (available at www.epa.gov/ne/nbh).

7. Volumes, Areas and Properties of Sediment by Management Units. 2003. Foster Wheeler report.

8. Dredged Material Management Plan (DMMP) EOEA No. 11669, Draft Environmental Impact Report (DEIR) for New Bedford and Fairhaven, Massachusetts. April 30, 2002. Prepared for Office of Coastal Zone Management, City of New Bedford, MA and Town of Fairhaven, MA. Prepared by Maguire Group Inc., Foxborough, MA.

9. New Bedford Harbor Superfund Pilot Study, Evaluation of Dredging and Dredged Material Disposal. May 1990. U.S. Army Engineer New England Division.

10. Declaration for the Record of Decision, New Bedford Harbor Superfund Site, Upper and Lower Harbor Operable Unit, New Bedford, Massachusetts. September 1998. U.S. Environmental Protection Agency - Region I, New England.

11. Final Sediment Monitoring Summary Report 2006 Remedial Dredging, Environmental Monitoring, Sampling, and Analysis, New Bedford Harbor Superfund Site, New Bedford Harbor, MA. May 2007. Battelle for USACE New England District.

12. Battelle Sediment Data Base.

The availability of existing data and the sources are summarized in Table 1.

Field Sampling

Pre-plan Dredging Scenario Analysis[4]

As the project proceeded from Phase 1 to the Field Sampling Plan the team discussed the impact of a five-year instead of a seven-year dredging schedule, to determine if sampling costs could be minimized (by collecting five instead of seven composites). The discussion further identified concerns that if modeling were based on a five-year assumption, but the actual schedule turned out to be seven years, that the modeling may not be representative, particularly if the upper harbor segments under the seven-year scenario exhibited much higher contaminant concentrations than they would under the five-year scenario.

In order to assess this possibility, and prior to preparation of the Field Sampling Plan, an analysis of dredging volumes and predicted composite sediment concentrations was conducted to estimate the range of average concentrations among the composites. This analysis used the estimated total dredging volumes (including over-dredge allowance) calculated for each DMU and reported in Foster Wheeler (2003 – Table 1) and sediment chemistry data from the NBHSS project database.

The first step involved discussion with EPA to determine which DMUs were being considered for placement in the CAD cells. This discussion confirmed that sediments from MU1-24 along with MF 102-104 would be isolated in an upper harbor CAD cell (if pursued in the future) and that MU25-37 would be directed to the LHCC. Thus, all DMUs in the Foster Wheeler table except for the four vegetated management units (labeled VU) were further considered.

The next step involved adjusting volumes in the Foster Wheeler-Table 1 to reflect the dredging progress since the original calculations were made. Several DMUs were assumed to be completely dredged (MU1, MU2, MU4, MU11) and others partially dredged (MU102, MU3, MU5, MU9, MU10) based on a 2004-2007 dredging footprint overlay (Figure 4). Based on this information, an estimate of the area remaining to be dredged for the DMUs was used to adjust the original volumes (Table 2). At the time this analysis was done (summer 2008), there was a possibility that portions of MUs 19-24 would be dredged in late 2008 and 2009 (personal communication with Dave Dickerson, NBH RPM, 28 July 2008). To account for this, it was estimated that about two-thirds of the volume of these MUs would be removed. In reality, the volume of dredging conducted in these MUs in 2008 and 2009 was considerably lower than projected in our planning analysis as funding from the American Recovery and Reinvestment Act (ARRA) of 2009 was used to redirect dredging to MUs farther north in the harbor.

[4] See footnote #1: the discussion in this section reflects the original as well as the revised scope of work.

The next step involved geographic grouping of the DMUs into the seven- and five-year scenarios. In the first scenario, the upper harbor would be dredged over five years with a lift of sediment placed into the upper harbor CAD each year and the lower harbor would be dredged over two years with the sediment lifts placed in the lower harbor CAD cell (Table 2, right column). The second scenario would involve accelerating the upper harbor dredging over a three-year timeframe while the lower harbor remained on the same two-year schedule (Table 2, second from right column). DMUs were then grouped based upon volume and geographic proximity to distribute the estimated volumes as evenly among the years (lifts) as possible. For the purpose of this analysis, dredging DMUs were assigned to one year or another with no splitting, although it should be recognized that actual operations may involve partial dredging of DMUs to achieve balanced volumes.

Once the DMUs had been grouped, estimated average values for total PCB (tPCB), Cu, TOC, and percent silt/clay were calculated for each DMU grouping (Table 3). In order to evaluate any differences between the two dredging scenarios and also to assess the impact that higher contaminant concentrations in the upper harbor might have on assumptions for subsequent modeling, two different estimates were created for the upper harbor lift scenarios. One a simple average of the individual DMU concentrations and the second a weighted average based on DMU volume (Table 4).[5]

Data for the DMUs considered not completely dredged were extracted from the NBHSS project database for tPCB, copper, TOC and grain size. Data were filtered to eliminate records with tPCB concentration values below 10 mg/kg, as these were unlikely to be dredged based on the project clean-up goals. Data were also filtered to eliminate those samples that were collected in portions of the DMUs on dates following dredging in those DMUs, as these would likely not represent sediments to be dredged in the future. The number of data points for tPCB ranged from 0 to 204 per DMU (Table 5). Copper (0-7), silt/clay (0-10), and TOC (0-7) had far fewer data points per DMU. Means and standard deviations were calculated for each DMU on tPCB, Cu, percent silt/clay, and TOC. The PCB mean plus two standard deviation data showed extreme heterogeneity in the upper harbor (Figure 5). Overall the tPCB data showed a downward trend from the upper to lower harbor (Figure 5), although Cu concentrations in the lower harbor were higher than in the upper harbor (Tables 3, 4, and 6). The extreme heterogeneity observed for tPCB was a result of DMUs which had one to five samples that were considerably higher than the remainder of the data for those DMUs. For example, DMU102 had one sample at 46,000 mg/kg out of the 59 data records while the next highest reported value was 4,800 mg/kg. DMU3 had five values of 26,000, 12,000, 12,000, 8,800, 7,300 mg/kg out of the 62 data records with all of the other 57 data points below 4,000 mg/kg.

The mean tPCB, Cu, TOC, and percent silt/clay data from each DMU were used to estimate the mean concentration of the five and seven lift scenarios. The average tPCB, Cu, TOC, and percent silt/clay for the two scenarios did not result in either scenario exhibiting markedly higher contaminant concentrations (Table 4). Both the five and three lift scenarios for the upper harbor

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[5] The calculation of the DMU group means from individual DMU means can produce a somewhat imprecise estimate of the true mean of the data, but was done for expediency and was considered acceptable for the planning level effort. Subsequent analysis of the DMU group means based on the individual data points across all DMUs in the group showed generally similar results to the “mean of means” analysis and is discussed later.

calculated that the average tPCB concentration in the first lift would be between 1,200 and 1,300 mg/kg with later lifts reflecting the down harbor gradient.

As mentioned earlier, the primary calculations involved a "mean of means" approach, but this was later followed up by averaging all data across each DMU grouping (true mean) in order to make sure that undue bias had not occurred in the initial analysis. Results of these calculations showed slight differences from the previous calculations (Table 6), but from a modeling perspective they were not considered to be of consequence. If there had been differences of an order of magnitude or more, then additional analyses might have been warranted.

As a consequence of these analyses, it was decided by the team to proceed with collection of sediment composites representing the five lift (five year) scenario. Modeling based on this scenario should conservatively represent the reasonably foreseeable range of dredging scenarios. The five groups of DMUs were then used as the basis for the Field Sampling Plan (Figure 6).

Sediment and Water Sampling

Sample collection was under the direction of the New England District and performed under contract by Jacobs Engineering. The contractor was required to prepare addendums to existing project work plans, including the Field Sampling Plan (FSP), Quality Assurance Project Plan (QAPP), and Site Specific Safety and Health Plan (SSHP) associated with the field sampling and data collection (Jacobs 2009b).

Sediment collection involved taking cores from 10 locations in each of five identified groups of DMUs to create five composite samples for analytical testing. Each composite sample was created by taking cores from 10 locations to estimated dredging depth. A volume weighted, stratified random selection process was used to select core locations within each group of DMUs. A total of 50 cores were collected as part of this effort. Sediment from each of the 10 locations per group was homogenized to create a single composite per DMU group.

The process used for core location selection was described in the FSP as follows:

> "Locating cores within DMUs was performed with the aid of GIS. For a DMU with one or more cores assigned, the average Z*[6] sediment thickness was calculated for that DMU, GIS was then used to identify Z blocks containing an average Z* thickness (+/- 0.5 feet). Of the Z blocks containing an average Z* thickness (+/- 0.5 feet) GIS was used to randomly select one Z Block and place the first core in that block. For DMUs with multiple cores the second core was randomly placed in a Z block identified as containing greater than average Z* sediment thickness. For a DMU with more than two cores, the third core was randomly assigned using GIS to a Z block containing less than the average Z* thickness of sediment. Several cores were manually shifted to avoid known obstructions such as power cables. Areas assumed to be dredged through 2009 were not considered for sediment core locations. In areas without Z* data, cores were placed randomly within DMUs using GIS. The number of cores placed in DMUs without Z* data was determined on a volume weighted basis similar to the DMUs with Z* data."

[6] "Z*" is the estimated depth of dredging from the design phase of the harbor cleanup

Sufficient sediment was taken in order to provide the necessary volume for the tests specified below and to provide five liters of sediment per composite (total of 25 liters) to ERDC for sequential batch leaching testing to be conducted in Vicksburg, MS. The samples were shipped within seven days of collection or within two days of compositing, as identified in the QAPP/FSP.

The contractor also collected water from the locations of the two CAD cells originally under consideration in NBH. Samples were collected from the mid-water depth for background water quality. Additionally, the contractor collected 50 liters of water from these locations for delivery to ERDC. This consisted of 30 liters from the upper CAD cell location and 20 liters from the vicinity of the LHCC location. This water was preserved and shipped by the contractor to ERDC as specified in the FSP. Pore water samples were collected using centrifugation and filtration. The total concentrations were analyzed following sample centrifugation and the dissolved concentrations were analyzed following filtration.

Sediment characterization was performed by GeoTesting Express, Katahdin Analytical Services, and laboratories at ERDC. GeoTesting Express performed the following geotechnical analyses: Moisture Content (ASTM D 2216), Specific Gravity (ASTM D 854), Grain Size Analysis with Hydrometer (ASTM D 422), Atterberg Limits (ASTM D 4318), Flexible Wall Permeability (ASTM D 5084), and Incremental Consolidation (ASTM D 2435). ERDC analyzed the composites for moisture content (ASTM D 2216) and organic content (ASTM D 2974). Both Katahdin Analytical Services and laboratories at ERDC conducted chemical analysis of the sediment composites and harbor water samples. ERDC laboratories also conducted Sequential Batch Leaching Testing (SBLT) (ASTM Method D-4793) on the five sediment composites to determine the partitioning characteristics of PCB and copper in the sediment. The results of the consolidation testing were used to develop void ratio-effective stress relationships and void-ratio permeability relationships for each of the five composites. The results of the SBLT were used to develop a single set of partitioning coefficients that are representative of all of the composites for PCB and copper. Results for PCB Aroclors 1242, 1248, and 1254 were reported by Katahdin Analytical Services, the ERDC laboratory, or both and the worst-case values for each Aroclor were used in the modeling.

Standard Elutriate Tests were also run on each of the five sediment composites using the appropriate proposed CAD site water to predict short-term losses during disposal. The tests were analyzed for elutriate total and dissolved concentrations of Total PCB (based on congeners), Aroclor 1242, Aroclor 1254, Cu, AVS, Oil and Grease, TPHs, Organic Carbon and also TSS (Jacobs 2009a).

Sample Collection

Samples were collected from New Bedford Harbor from 30 March to 8 April 2009 (Jacobs 2009a). Sediment samples were collected using a vibracore by CR Environmental, a subcontractor to Jacobs Engineering. In addition to the fifty cores, a field duplicate was also collected from DMU group 3. Three sediment samples were also taken from cores in DMU group 1 following alarm indications from the photoionization safety detector that indicated the likely presence of volatile organic compounds. Chemistry, geotechnical, and core log data were presented in Jacobs (2009a).

Copper and tPCB values for the five sediment composites showed comparable trends to those calculated from the historic data as originally shown in Table 6; however, the 2009 composite tPCB data were generally lower than the calculated means of the historic data (Table 7). In contrast, 2009 copper data were generally greater than the historic mean calculations.

Testing and Analysis

Consolidation Testing

GeoTesting Express performed Incremental Consolidation (ASTM D 2435) on the five composites, measuring the void ratios and strains at loadings ranging from 0.01 tons per square foot (tsf) to 8 tsf and calculating the coefficient of consolidation. Using the measured void ratios and strains and the calculated coefficient of consolidation for each loading, the permeability of the sediment was computed for each loading and its corresponding void ratio. For each sediment composite, the results were then fitted to create relationships between void ratio and effective stress and between void ratio and permeability. The results are shown in Figures 7 through 11.

Sequential Batch Leaching Testing

ERDC laboratories conducted SBLT (ASTM Method D-4793) on the five sediment composites in duplicate to determine the partitioning characteristics of PCB and copper in the sediment. In addition to Aroclors 1242 and 1254 as originally planned for analysis, ERDC also determined concentrations of Aroclor 1248. Four cycles were used for PCB and seven cycles were used for copper. The results for four cycles and replicates are given in Table 8 and the three other cycles, which exhibited small changes relative to the first four, are provided in the appendices. The results of the SBLT were used to develop a single set of partitioning coefficients that are representative of all of the composites for PCB and copper. Analysis of the test results yield a K_{oc} of 550,000 L/kg for Aroclor 1248 and 210,000 L/kg for Aroclor 1254 and a K_d of 18,200 L/kg for Copper. Where possible, additional partitioning coefficients were computed from the results of the pore water analysis performed on the sediment composites by Katahdin Analytical Services for Jacobs Field Services (2009a). These analyses were used to confirm the results of SBLT. The analysis yielded a K_{oc} of 39,400 L/kg for Aroclor 1242 and 202,000 L/kg for Aroclor 1254 and a K_d of 21,400 L/kg for Copper. The K_{oc} values for the PCB were within a factor of four of typical values reported in the literature.

4 — Modeling

Modeling Assumptions

This report presents modeling results for the lower harbor CAD cell (LHCC) based on EPA's priority for site evaluation. Since a LHCC is only in the evaluation stage, a preliminary design was not available; therefore, a generic design was developed based on review of the existing CAD cells that have been created by the City of New Bedford and the design report for the upper harbor CAD cell (Apex and Jacobs 2006). The general location of the LHCC is shown as CAD Cell 2 in Figure 2. The generic design used in the modeling for the LHCC had a 650' x 650' surface footprint and a maximum depth below the surrounding harbor bottom of 47 feet as shown in Figure 3. Side slopes for the first seven feet of CAD were set at 1V:6H and for the remaining 40 ft of depth we used 1V:3H. Due to the sloping sides, the CAD cell was divided into 4 sections for modeling consolidation and short-term contaminant loss after capping as shown in Figure 12. The center section comprises 31% of the area and 51% of the storage. Rings 1, 2 and 3 each comprise 23% of the area, but 30%, 15%, and 4% of the storage, respectively.

The disposal operation assumed for the LHCC consisted of mechanical dredging of sediment into 500 cubic yard split hull (bottom dump) barges. Disposal into the CAD cell was based on placement in 500 cubic yard increments from a barge with a draft of eight feet and a hopper 88 feet long; three barge dumps per day was assumed. A scaled schematic of the disposal operation and CAD cell is shown in Figure 3. The barges were assumed to contain about 15% captured water and 85% sediment by volume. The dredged material is assumed to entrain additional water during placement from the descent through the water column and the collapse and spreading of the material on the bottom. The quantity of water that is entrained is a function of the water column depth. More water will be entrained initially when the CAD cell is empty than at the end when the CAD cell is almost full because the discharge will have greater energy and time to entrain water when the CAD cell is less full. Much of the entrained water will be released during the dredging season as the placed material settles and consolidates.

The filling schedule for the LHCC was assumed to consist of Composite 3 sediment in the first year (Time 0; Note: only a portion of the area represented by Composite 3 is envisioned for LHCC disposal). In the next year Composite 4 sediment is placed in the LHCC covering the Composite 3 dredged material, and then the CAD cell is left idle until the next dredging season. Two years after placing the first material, Composite 5 sediment is placed in the LHCC covering the Composite 4 dredged material. The CAD cell is then left idle until the next construction season when the CAD cell is capped with unwashed sand, maintaining the content of fine-grained and organic material. Negligible new deposition on top of the CAD material from outside the CAD cell via bottom load or suspended load is assumed. Similarly, negligible erosion or resuspension of bed sediments or cap materials from the CAD cell is assumed.

During filling, dredged material will be stripped and resuspended from the discharge, releasing both particulates with their associated contaminants and pore water with its dissolved contaminants. The pore water will also contain dissolved organic carbon (DOC) and contaminants associated with the DOC. Facilitated transport of contaminants is not specifically assumed, but the partitioning coefficients developed from the SBLT and pore water analysis include the partitioning associated with the DOC as being part of the dissolved contaminants. The particulates, while suspended, partition their contaminants with the CAD cell water. The suspended particulates slowly flocculate and then settle in the CAD cell, leaving the dissolved contaminants and DOC to accumulate in the CAD cell water. However, new particulates are introduced into the water column two or three times per day during the placement season, creating a near steady suspended solids concentration that increases slowly throughout the season and then decreases in the week or two following cessation of placement operations.

The currents in the CAD cell below the top few feet are assumed to be too low to transport particulates to the surface or to resuspend bedded material. Releases from bedded dredged material are limited to pore water expulsion and diffusion. Bioturbation is assumed only in the long-term evaluation after capping. Water and contaminant exchange are assumed in the upper few feet of the CAD cell by turbulent mixing and by displacement during material placement. After material placement operations cease for the dredging/construction season, diffusion of contaminants from the lower water column to the upper water column of the CAD cell is assumed to occur.

For consolidation modeling purposes, the material placed in a placement season is represented as a single lift at the end of the placement season. The volume of the lift and its void ratio are estimated based on the placement operation and the characteristics of the sediment composite, incorporating the entrainment and densification that occurs during the placement season. The lift is assumed to contain the entire mass of sediment particles dredged, i.e. there were no losses of particulates.

After placement is completed and the dredged material and suspended solids have been allowed to settle and densify, a cap will be placed to close the CAD facility. The required cap thickness is dependent on the cap design objectives, accounting for bioturbation, consolidation, erosion, and operational considerations. For the purposes of this evaluation, the cap thickness was set to be 3 feet. Unwashed, natural sand was chosen for the capping material, which would typically have a small fraction of organic carbon and fines that would improve the retardation of contaminants in the cap.

Modeling Results

<u>Sizing and Filling</u>

A cut and fill spreadsheet analysis (given in Appendix B) was perform to determine the size of CAD cell needed to contain the proposed volume of dredged material and to estimate the lift thicknesses of the annual fills for consolidation analysis. A 650’ x 650’ surface footprint was selected with a side slope of 1V:6H for top 7 ft of depth and 1V:3H for the remaining 47 ft of depth below the existing sediment surface. The volume of the CAD cell was computed using the formula for the volume of a truncated square pyramid. The volume of each foot of the inverted pyramid was used to compute the average thickness of each lift of material in each of the four modeling sections of the CAD cell shown in Figure 12. The analysis showed that a 650’ x 650’ surface footprint for the CAD cell would be sufficient to contain the first two lifts (years) of dredged material without bulking and the third lift of dredged material with bulking and provide some freeboard to insure sediment retention and volume for cap placement. Additional freeboard will develop as the dredged material releases its entrained water and consolidates under the loading of the dredged material and capping material.

Consolidation

The consolidation of the dredged material after placement in the CAD cell was analyzed using the USACE PSDDF model. Due to the sloping side walls of the cell, the consolidation was analyzed in four sections as shown in Figure 12. The PSDDF model results showed that the CAD cell size was appropriate to contain the proposed volume of dredged material, considering the entrainment of water in the dredged material, the volume of capping material, spreading of dredged material from the placement dynamics, suspended solids retention, and consolidation prior to capping. The consolidation results were analyzed to determine the predicted pore water expulsion rates for contaminant loss predictions both prior to and after capping.

The CAD sizing analysis showed that the center of the lower harbor CAD cell would be filled with 42 ft of dredged material based on its in situ density. However, analysis of potential water entrainment in the dredged material during both dredging and placement through the water column yielded an estimate of bulking or entrainment that would result in placement of 52 ft of dredged material. The annual lifts and their void ratios are given in Table 9. With 3 ft of capping material, a total of 55 ft of material in our cell that is 47 ft deep. However, the PSDDF model predicted that in the center section of the CAD cell, 10.3 ft of pore water would be expelled from the placed dredged material prior to capping, primarily from the 10 ft of water that was predicted to be entrained during dredging and placement through the water column (mostly at depth from the first lift placed). The fill height of the center section as a function of time is shown in Figure 13 and the fill heights of all four sections after capping are shown in Figure 14 (Note that Time 0 in Figure 14 is after capping whereas Time 0 in Figure 13 is from the start of filling). Therefore, as shown in Figure 15, the depth of fill immediately after capping is approximately 45 ft, providing a freeboard of 2 ft. After capping, an additional 7.2 ft of pore water is predicted to be expelled in the first 10 years, 9.4 ft of pore water in the first 20 years and 10.9 ft of pore water in the first 40 years. At 40 years after capping, the dredged material is predicted to be 94% consolidated. Based on the PSDDF model results, much of the contaminant losses would be expected to occur during placement and prior to capping.

Placement

The open water placement of dredged material in the LHCC was modeled using the USACE STFATE model to predict the entrainment of water in the deposited dredged material, the mass of dredged material suspended in the water column, the suspended solids concentration in the water column, the settling time, and the vertical and lateral distribution of suspended solids following a barge discharge of dredged material. STFATE model runs were conducted on 500-cubic yard barge discharges at the beginning and end of each dredging season to simulate the range of placement impacts for each dredging season and to estimate annual contaminant losses during placement. Results for placements between the beginning and end were assumed to produce results linearly between these two extremes. The predicted resuspension of fine-grained dredged material is shown in Table 10. The STFATE model results indicate that about 3 to 4% of the fine-grained fraction of the dredged material remains in suspension about 3 to 4 hours after the barge discharge and disperses in the CAD cell water below the loaded draft of the barge, resulting in predicted average TSS concentrations ranging from about 20 mg/L for the first lift to 150 mg/L for the third lift. In a shallow saline environment such as New Bedford Harbor and the CAD cell, the TSS concentration will typically decrease to 50 mg/L within a day and to 10 mg/L within a week. However, this should be regarded as a generalization as recent monitoring of a CAD cell in New Bedford Harbor (Dragos 2009) observed suspended solids levels returning to background typically within two hours.

The discharge plume collapse dynamics were modeled using the USACE SURGE to examine whether the momentum of the discharged material was sufficient to cause the dredged material to run up the side slope and out of the CAD cell. All discharges are assumed to be within the area of the level bottom, a 326-ft square, and no closer than 160 ft horizontally from the lip of the CAD cell. The dynamics were examined for all three sediment composites across the range of water depths that would exist during their placement. In all cases the discharged material is not predicted to run up the slope above a depth of about 11 ft below the lip (vertically) or about 55 ft from the lip (horizontally). The results of the collapse modeling are given in Table 11. Therefore, the CAD cell is expected to be capable of confining the dredged material during placement due to the shallow water depth at the site limiting the plume acceleration during descent.

CAD Cell Hydrodynamics

Mixing within the CAD cell will affect the settling of resuspended dredged material and loss of dissolved and particulate-associated contaminants by the placement operations. The nature and intensity of the mixing is a function of the hydrodynamic regime of the site and the CAD cell configuration. Hydrodynamic modeling of New Bedford Harbor was recently conducted to examine sediment and PCB transport. This modeling examined the tide-induced circulation in the proposed lower CAD cell using the general vertical coordinate (GVC) version of EFDC (Environmental Fluid Dynamics Code), which is a 3D public domain surface water modeling system that invokes the hydrostatic pressure assumption (Hamrick, 2007a,b,c,d). The modeling yielded only low velocities in the water column above the CAD cell, typically less than 0.3 fps. The velocity is sufficient to rapidly exchange the water above the CAD cell, typically in one to three hours. The modeling was not sufficient to predict the extent of mixing below the lip of the CAD cell. Therefore, the model was adapted to include the CAD cell with a higher resolution grid to examine the potential mixing in the CAD cell.

The curvilinear-orthogonal grids for the higher resolution EFDC modeling are shown in Figures 16 and 17. This figure shows that the CAD cell is represented using 32 cells, with the size of each cell being approximately 44 m in the lateral direction and 23 m in the longitudinal direction. The lateral/longitudinal directions are with respect to the general north-south orientation of the harbor, with the lateral direction being in the east-west direction. The New Bedford Harbor model used five layers for all grid cells except those used to represent the CAD cell. A vertical slice through the grid along the centerline of the CAD cell is shown in Figure 18. As seen in this figure, 20 vertical layers are used to represent the water column for the eight cells at the center of the CAD cell, and 9 or 13 cells are used in the cells that represent the side slopes of the CAD cell. The use of more vertical layers in the deeper CAD cell allows for a more accurate prediction of the vertical circulation below the lip of the CAD cell.

The EFDC model was run for seven days using a 0.5-sec time step. The tide-induced circulation during the last day of this model run was used to estimate the residence time of water within the CAD cell. Figure 19 shows the vertical velocity distribution in the CAD cell at one time step during an ebb tide. A vertical eddy is seen on the right (i.e., north) side of the CAD cell that is about half the length of the CAD cell in width. The eddy extends approximately 4 m below the lip of the CAD cell. Figure 20 shows a small eddy centered at about 3 m below the lip of the CAD cell in the middle of the cell. The surface velocity vectors indicate that this is near the end of flood tide as the flow direction has already changed to the left (i.e., south) of the CAD cell whereas the flow is still flooding on the north side. An analysis of the tide-induced circulation in the CAD cell indicated that the velocities in the lower half of the CAD cell are very small, typically less than 0.1 ft/s, and as such, mixing with the water in the upper half of the cell will be extremely limited during fair weather conditions. Higher velocities and therefore enhanced mixing would occur during high wind conditions and during heavy rainfall events, e.g., nor'easters, as the runoff into the upper end of the harbor will be significantly increased.

Short-Term Partitioning and Contaminant Loss

Contaminants associated with the TSS resulting from resuspension during placement will partition with the CAD cell water. It is unlikely that the partitioning reaches equilibrium before the particles interact with particles from subsequent discharges, flocculate and settle. Most particles will remain in suspension less than a day. The kinetics of PCB desorption in a stagnant water column is sufficiently slow that it may take weeks to reach equilibrium; however, 10 to 20% of the PCB may desorb in the first day (Gong, et al., 1998; Ghosh, et al., 1999). The partitioning of contaminants to the CAD cell water from the resuspension of the large number of discharges in a dredging season is predicted to be sufficient to achieve a contaminant concentration approximately equal to the pore water concentration of the sediment or dredged material. The predicted dissolved and total concentration of contaminants in the CAD cell as a function of time based on the resuspension and partitioning model results are shown in Figures 21 through 24. The total concentration at the top of the CAD cell will be somewhat lower because the TSS at the top will be appreciably lower than the average for the first two lifts.

The dissolved contaminants and particulate-associated contaminants in the upper portion of the CAD cell will be lost as the CAD cell water is displaced by subsequent barge discharges. The displacement volumes are likely to be about 15 to 20% greater than the volume of sediment being dredged due to entrained water in the mechanical dredge/excavator bucket or overdredging. This would amount to about 50,000 cubic yards in Year 1, 180,000 cubic yards in

Year 2, and 150,000 cubic yards in Year 3; the corresponding target volumes of sediment dredged would be 44,000, 155,400 and 126,200 cubic yards, respectively. An additional 25,000 cubic yards of CAD cell water will be displaced in Year 4 by cap placement. The average contaminant concentrations and mass loss for each lift and contaminant are given in Tables 12 and 13, respectively.

Hydrodynamics modeling yielded only low velocities in the water column above the CAD cell, typically less than 0.3 fps. The velocity is sufficient to rapidly exchange the water above the CAD cell, typically in one to three hours. However, the velocity is sufficiently low to limit mixing in the CAD cell water. Nevertheless, the higher resolution hydrodynamic modeling using the GVC version of the EFDC model showed a potential to establish a slow vertical eddy circulation predominantly in the top ten feet of the CAD cell sufficient to promote turbulent diffusion and slow exchange with the water column above the lip of the CAD cell. The increase in contaminant losses from the CAD cell from this mixing is small because discharge losses during placement is small in the top ten feet of the CAD cell during placement of the first two years of disposal. The predicted TSS in the top two feet is shown in Figure 25 along with the average TSS concentration in the CAD cell.

The predicted losses of PCB (Aroclors 1242, 1248 and 1254) by the placement operations (resuspension and discharge) during the three years of filling the LHCC are 310 g in Year 1 (sediment composite 3), 1,050 g in Year 2 (sediment composite 4) and 1,120 g in Year 3 (sediment composite 5), about 0.038% of the total PCB mass removed from the associated dredging. The released PCB are about 81% Aroclor 1242 (mass loss about 0.06%), 5% Aroclor 1248 (mass loss about 0.009%) and 14% Aroclor 1254 (mass loss about 0.018%). The 0.035% mass loss is a weighted average based in the relative contribution of each Aroclor release (81%, 5%, and 14%) to the total release and their respective mass loss rates (0.06%, 0.01%, and 0.02%). About 85% of the released PCB is predicted to be dissolved. These losses were computed by averaging the predicted concentrations shown in Figures 21 to 23 for each lift and then multiplying the averages by the volume of CAD water displaced by each lift given above.

The predicted losses of copper during the three years of filling the LHCC are 1.9 kg in Year 1 (sediment composite 3), 7.5 kg in Year 2 (sediment composite 4) and 34.7 kg in Year 3 (sediment composite 5), about 0.020% of the copper. About 50% of the released copper is predicted to be dissolved. These losses were computed by averaging the predicted concentrations shown in Figure 24 for each lift and then multiplying the averages by the volume of CAD water displaced by each lift given above.

Contaminant losses from the CAD cell after placement of the annual lift is driven by turbulent diffusion from the CAD cell to the upper exchangeable water column. The annual loss of contaminants by turbulent diffusion from the lower water column is limited to about the top 118,000 cubic yards (10 feet) of contaminated CAD cell water after the annual placement operation ceases. The CAD cell is expected to contain about 3.3 kg of PCB and 15 kg of copper in 348,000 cubic yards of CAD cell water after Year 1, 1.0 kg of PCB and 6.8 kg of copper in 192,000 cubic yards of CAD cell water after Year 2, and 0.4 kg of PCB and 7.0 kg of copper in 71,000 cubic yards of CAD cell water after Year 3. Following cap placement, the contaminants in any remaining CAD cell water will be lost by turbulent diffusion. If all of the contaminants remaining in the top 118,000 cubic yards of CAD cell water after each year of placement were lost by turbulent diffusion, 2.0 kg of PCB and 13 kg of copper would be lost by turbulent diffusion from the CAD cell water contaminated during dredged material placement.

An additional potential loss of contaminants is the displacement of CAD cell water in the fall or winter by cold dense water sinking into the CAD cell. However, due to the shallow depth of the overlying water column and the mixing that would occur, this mechanism is likely to limit the exchange to no more than 5 feet of water or 71,000 cubic yards in the CAD cell. This would limit the losses to about 20% of the contaminants in the CAD cell water between dredging seasons. Any losses between dredging seasons would be partially offset by decreasing the predicted losses during the next dredging season because the initial contaminant concentration in the CAD cell water at the start of the next dredging season would be lower.

The overall potential contaminant losses resulting from placement are 1.9 kg PCB and 9.5 kg copper from Year 1, 1.9 kg PCB and 13.4 kg copper from Year 2, and 1.4 kg PCB and 40 kg copper from Year 3. These quantities represent the sums of the potential losses by the various mechanisms presented above, which when totaled across all three years equals 5.2 kg PCB and 62.5 kg copper. These losses represent 0.08% of the three PCB Aroclors (0.13% of Aroclor 1242, 0.02% of Aroclor 1248 and 0.03% of Aroclor 1254), and 0.03% of the copper placed in the CAD cell.

Long-Term Contaminant Loss from Capped CAD Cell

The contaminant fate and transport from the capped CAD cell were evaluated in two parts. The first part was evaluated during the period of dredged material consolidation using the USACE CAP model, which considers pore water advection induced by consolidation. The consolidation flux and contaminant flux were estimated for the four major areas of the CAD cell (Center, Ring 1, Ring 2, and Ring 3) as shown in Figure 12. In the center section, ninety percent of the consolidation is completed only after 30 years, but meaningful contaminant transport by pore water expulsion is limited to the first two to four years. The three rings contribute contaminant flux over a shorter period of time as compared to the center area of the pit. The consolidation fluxes (pore water expulsion) predicted by the PSDDF model are shown in Figure 26. The second part was evaluated for the long term, after significant pore water advection ceases. During the long term, contaminant transport is dominated by diffusion of contaminants from the dredged material and into the cap. Long-term contaminant fate and transport from the capped CAD cell was modeled without considering contaminant degradation or transformation using the USACE RECOVERY model.

The predictions of long-term contaminant flux from a CAD facility require the physical and chemical characterizations of the dredged material and capping materials. The CAP model for prediction of contaminant flux requires a chemical description of the materials and contaminant partitioning characteristics between the pore water and materials. The chemical characterization and partitioning data are given in Table 14. The contaminant concentrations represent the results of a weighted average composite of the contaminated dredged materials (sediments) in the three composite materials envisioned for the LHCC. Figure 15 shows the material thickness immediately after the placement of the cap.

The CAP model was run on four separate sections of the CAD cell due to differences in dredged material thickness and predicted settlement. Each section represents about one quarter of the area of the CAD cell, with the center section being 31% of the area and each ring being 23% of the area. The first section represents the center of the CAD cell and includes the entire part of the cell that has a level bottom, plus the beginning of the side slopes. The next three sections are concentric bands around the center covering the remainder of the sloped area of the CAD cell. Each band has successively thinner dredged material thicknesses and smaller settlements; the thickness and cumulative settlement of the four sections after capping are shown in Figures 27 and 28 as a function of time. The physical and chemical properties of the three composite materials and the capping material as well as the layer structures for the four sections examined with the CAP model are shown in the conceptual model schematics in Figures 29 to 32.

Contaminant fluxes associated with the advection of water resulting from dredged material consolidation were estimated for a 47-ft deep LHCC using the CAP model. The CAD pit will expel water only upward for the four cell sections as the native harbor bottom sediments forming the walls of the CAD have very low porosity relative to the dredged sediment and therefore the native sediments will resist flow of pore water. Figure 33 shows the flux of Aroclor 1242 (the most mobile of the contaminants) for all four sections during the period of significant advective flux. Figure 34 shows the surficial sediment concentrations in the CAD cell of Aroclor 1242 for all four sections of the cap during the same period. All four sections yield similar fluxes and surficial sediment concentrations for Aroclor 1242; the same is true for the other contaminants of concern. Therefore, the fluxes and surficial sediment concentrations for the other contaminants are only shown for the center section in Figures 35 to 38. All of the predicted fluxes and surficial sediment contaminant concentrations are very small. The flux of contaminants is equivalent to less than 1 gram per year and surficial sediment concentration of contaminants in the cap at the end of the advection dominated period (fifty years after being capped) are about six orders of magnitude smaller than the concentration in the capped sediment. The cap contaminant concentrations fifty years after being capped are predicted to be 7 ng/kg (parts per trillion) Aroclor 1242, 0.00003 ng/kg Aroclor 1248, 0.003 ng/kg Aroclor 1254, and 100 ng/L copper.

The CAP model results showed that the contaminants transported from the dredged material by pore water advection and diffusion would be contained in the bottom of the cap. This is true for all sections of the cap, even in the center section, which had the largest settlement. The contaminant and sediment profiles from the end of the CAP model runs were used as the initial conditions for the long-term, diffusion dominated modeling using the RECOVERY model.

The RECOVERY model was run for a 500-year period of simulation for each contaminant and each section. The performance of each cap section are essentially identical since the upper profile of the section with respect to cap and sediment properties are identical as shown in Figures 29 to 32. To show the long-term performance of the cap, the predicted surficial sediment concentration of Aroclor 1242 is shown in Figure 39. Aroclor 1242 is a conservative representative of all of the contaminants because it is the most mobile. Comparing Figure 39 with Figure 34 shows that the predicted surficial sediment concentration at 500 years is 10 times the concentration predicted at 50 years, indicating that the surficial sediment concentration, flux and pore water concentrations increase nearly linearly. The concentrations predicted for the bioactive zone (i.e., top four inches of cap) throughout the first 500 years of cap life are more than 6 orders of magnitude lower than the concentrations in the sediments being capped.

Figure 40 shows the predicted ratio of Aroclor 1242 concentrations of the pore water in the bioactive zone compared to that below the cap by the RECOVERY model for 500 years. The ratio shows the effectiveness of the cap in reducing contaminant exposures in both the benthic zone and water column. Figure 40 shows that the cap reduces contaminant exposures by at least 6 orders of magnitude throughout the first 500 years. At 500 years, the pore water concentration of dissolved Aroclor 1242 in the bioactive zone of the cap was predicted to be 0.006 ng/L (parts per trillion).

Contaminant breakthrough of the 3-foot cap, defined here as a bioactive zone (mixed layer) pore water concentration greater than 0.01% of the initial sediment pore water concentration (a concentration approaching the long-term risk goal; e.g., 0.01% of 7 ppb PCB or 0.0007 ppb PCB), did not occur in our simulations of 500 years. The simulations were extended to 5000 years and breakthrough was predicted for Aroclor 1242 at 1800 years and copper at 4800 years. The copper concentration achieved its long-term peak cap pore water concentration of 12.3 ng/L at 6500 years. The breakthrough times for Aroclor 1248 and Aroclor 1254 are greater than ten thousands years. Since about 11 ft of settlement is predicted for the center section of the CAD cell, there is a very large potential for up to 11 ft of burial over the life of the CAD cell. If this burial were considered in the long-term fate and transport modeling, the CAD cell would be effective for all contaminants for a much longer period, tens of thousands of years. The three-foot cap thickness assumed for the CAD facility is predicted to be an effective isolation layer for all of the contaminants of concern.

Impacts of an Accelerated Filling Schedule

In the event that project implementation allows for a faster filling schedule (i.e., one or two years for filling rather than the three years of filling modeled) the following discussion estimates the likely impact of such a schedule change. This accelerated schedule was not modeled, but the impacts of using an accelerated schedule can be estimated from the modeling for the original schedule. The likely impacts are:

1. An accelerated schedule would reduce the time available for consolidation of the dredged material after placement in the CAD cell and prior to capping. Examination of the rate of consolidation indicates that consolidation prior to capping could be reduced from about 10.3 ft to about 5 or 6 ft. This would mean that a larger CAD cell would be needed to hold the dredged material and control losses during placement, approximately a 700-ft square instead of a 650-ft square.
2. Since the dredged material will occupy a greater volume prior to capping, it will displace more CAD cell water that will be contaminated by resuspension. The quality of the CAD cell water is not likely to change from the quality predicted for the original schedule because it is predicted to be in equilibrium with the dredged material. Therefore, the increase in placement losses is likely to be in proportion to

3. Accelerating the placement schedule will increase the number of loads or the size of the loads. Preferably, the size of the loads will be increased to minimize traffic and improve efficiency. Increasing the number of loads would permit less time for settling and increase the surface water displacement and disturbance by barges and tugs, resulting in an additional loss of suspended sediment and associated contaminants. Increasing the size of the load would have a less detrimental effect on settling and loss of suspended sediment. Larger loads are released deeper in the water column, have less entrainment of water during its descent to the bottom of the CAD cell, and maintain a greater density difference to provide stability on the bottom.
4. Contaminant losses after placement will be greatly reduced because very little CAD cell water would remain after the first year of filling, as little as 3 to 10 ft depending on whether additional filling is done in the second year. In the original schedule, a total of about 28 ft of CAD cell water was predicted to be lost over the three years of placement, yielding a reduction in post-placement losses of about 65 to 90%. This would reduce after-placement losses from about 2.5 kg PCB to 0.3 to 0.9 kg PCB and from about 14 kg Cu to 1.4 to 5 kg Cu.
5. Accelerating the placement schedule is estimated to result in a net decrease in PCB loss of 1.5 to 2 kg and net decrease in Cu loss of 1 to 4 kg. However, this savings may not be realized if adequate settling is not maintained due to a loss of quiescent settling time by more frequent disposal events.
6. A reduction in consolidation prior to capping will increase the quantity of consolidation after capping and increase pore water expulsion through the cap. However, the additional mass of contaminants in the pore water expulsion is very small and is not estimated to meaningfully impact the long-term contaminant loss after capping or contaminant breakthrough.

5 — Discussion

Modeling Results and Field Plume Surveys

The modeling results appear to be a reasonable and conservative representation of the behavior of actual plumes. In a separate study, plume monitoring was conducted on five separate events that placed New Bedford Harbor sediment into one of the existing City of New Bedford CAD cells (Dragos 2009). The CAD surveyed had a maximum depth of about 37 feet. The entire CAD cell was surrounded by a silt curtain with access of vessels controlled by one section of the curtain which was used as a gate. Plume monitoring used Acoustic Doppler Current Profilers (ADCP) to measure acoustic backscatter from sediment in the water column and direct water sampling of total suspended solids (TSS) to calibrate the acoustic data. The five events included one occasion in April, three occasions in May, and one in July 2009. Plume transects were conducted by two separate vessels inside and outside of the silt curtain. Monitoring of the plume during these events began before disposal and continued up to 0.75 hr to 1.5 hr after disposal.

Results from the plume monitoring showed initially intense plumes throughout much of the water column within the CAD cell shortly after disposal with maximum measured TSS of 226 mg/l (May 27, 2009 event) and ADCP interpolated values of similar magnitude. In all cases, the plumes were shown to rapidly settle and generally remain within the CAD cell. Results reported from surveys collected approximately 50 minutes following disposal showed plumes as ranging in TSS concentrations from background levels to 50 mg/l and limited largely to the bottom of the CAD.

Although detailed comparison of the model results to the field results was beyond the scope of the present effort, a quick comparison to model results from one of the STFATE model runs was conducted. The model run analyzed used sediment from composite 3 placed into a CAD cell 37 feet deep (by this time the simulated CAD was partially filled), similar to the actual CAD that was surveyed. Results from model output 50 minutes after disposal showed similar, although somewhat higher TSS values than reported by Dragos (2009). Model values showed plume maximums of 8 mg/l TSS at a 3 ft depth, 56 mg/l at 15 ft, 135 mg/l at 25 ft, and 257 mg/l at 35 ft. Based upon this quick analysis it appears the model provides a reasonable projection of plume behavior and possibly a moderate over-prediction of TSS levels.

Relative Magnitude of Contaminant Losses and Uncertainty

The contaminant losses from a CAD cell to the overlying water column are predominantly associated with placement. These losses represent 0.08% of the total mass of PCB disposed in the cell (0.13% of Aroclor 1242, 0.02% of Aroclor 1248 and 0.03% of Aroclor 1254), and 0.03%

of the total mass of copper placed in the cell. The losses are driven by partitioning and the CAD cell water is predicted to approximate the pore water of the sediments being placed. The partitioning results agree well with the measured pore water concentrations, providing confidence in the predictions. The losses would be greater if there were significant exchanges of CAD cell water with the overlying water column on a periodic basis, e.g., in response to storms. These exchanges are not expected, but provide a source of uncertainty. A silt curtain around the perimeter of the CAD cell, if designed to divert flow around and not under the curtain, should help to minimize these exchanges.

The predicted short-term losses are small in comparison to typical losses from mechanical dredging, which range from 0.5 to 2% (Palermo et al., 2008). The placement losses are predicted to be 1 to 2 orders of magnitude smaller. Even when considering all of the uncertainties of dredged material placement, the losses from placement are expected to be much smaller than the losses from dredging.

The long-term contaminant losses after capping are insignificant, even during the initial period (3 years) following cap placement when expulsion of pore water from consolidation is the dominant driver for contaminant transport. As long as the cap is stable and isolation is provided, the long-term losses will be negligible for thousands of years. The only uncertainty in the prediction is the assumption of long-term stability and isolation; however, since the dredged material is predicted to consolidate eleven additional feet after capping, the CAD cell should become more and more stable. In addition, the depression formed by this consolidation will provide a sink for additional sediment deposition, which will increase the “cap” thickness and maintain long-term isolation.

The long-term contaminant losses from the CAD cell is very likely to be controlled by the deposition of new sediment onto the CAD cell cap. The new sediment should resemble the background sediment surrounding the CAD cell and would be expected to have a much higher contaminant concentration than would ever result from diffusion of contaminants from the capped dredged material.

6 — Conclusions

1. A 650-foot square CAD cell excavated 47 ft below the existing sediment surface is sufficient in size to hold and cap the sediments proposed for a lower harbor CAD cell and to contain the lateral spread and collapse of the dredged material discharge during placement.

2. About 10 ft of water will be entrained in the dredged material during placement, but all of this water is predicted to be expelled from the consolidating dredged material during the three years of placement.

3. An additional 11 ft of settlement and pore water expulsion is predicted to occur after cap placement.

4. Dredged material resuspension will occur during placement, resulting in predicted TSS concentrations ranging from 20 to 150 mg/L and both dissolved and particulate-associated contaminant release to the water column overlying the CAD cell.

5. The resuspension predictions appear to be a reasonable and conservative representation of the behavior of actual plumes observed during similar dredged material placement in a City of New Bedford CAD cell in 2009.

6. Dissolved contaminant concentrations in the CAD cell water (but not the overlying water) during filling will become approximately equal to the sediment pore water being placed in the CAD cell.

7. About 2.4 kg of PCB are predicted to be lost during dredged material placement in the lower harbor CAD cell, 85% of which would be dissolved. About 44 kg of copper are predicted to be lost during dredged material placement, 50% of which would be dissolved. These losses represent about 0.038% of the total PCB mass and 0.020% of the total copper mass being placed into the CAD cell.

8. Hydrodynamics modeling yielded only low velocities in the water column above the CAD cell, typically less than 0.3 fps. The velocity is sufficiently great to rapidly exchange the water above the CAD cell, typically in one to 3 hours. The velocity is sufficiently low to limit any mixing in the CAD cell water, mostly in the top few feet. However, higher resolution hydrodynamic modeling of the CAD cell environ performed using the 3-D EFDC model set up for sediment transport modeling showed the potential to set up a slow vertical eddy in the CAD cell. The eddy could provide slow mixing to a depth of 10 feet below the lip of the CAD cell. Therefore, contaminants in the top ten feet of the CAD cell were subjected to turbulent diffusion and exchange with the water column above the lip of the CAD cell.

9. Additional losses due to potential turbulent diffusion and thermally induced displacement over the winter between dredging seasons could result in about 2.7 kg of additional PCB being lost from the CAD cell water prior to capping, resulting in a total loss from placement operations of 0.08% (5.2 kg) of the total PCB mass disposed in the cell. Similarly, an additional loss of about 18 kg copper could be lost by these mechanisms, resulting in a total placement loss of about 0.028% (63 kg) of the total copper mass disposed in the cell.

10. Placement losses are predicted to be one to two orders of magnitude less than typical losses from mechanical dredging operations.

11. After capping, the contaminants expelled from the dredged material by consolidation would be contained in the lower foot of the cap.

12. Without consideration of burial (i.e., the additional sediment deposition that will take place over time into the bowl-shaped CAD cell depression formed by consolidation after the cap is placed), contaminant breakthrough will take more than 1800 years. Again, breakthrough, as used here, is defined as the condition when the contaminant flux or surficial pore water concentration increases to levels of 0.01% of the original flux or sediment bed concentration before dredging and disposal. With burial promoted by the estimated ten feet of post-cap dredged material settlement, the transport of contaminants through the cap and burial material will take tens of thousands of years to achieve the breakthrough.

13. A stable 3-ft cap would be highly effective in isolating the contaminated dredged material.

14. Acceleration of the placement schedule would increase the size of the CAD cell needed to contain the 325,000 cubic yards of sediment proposed for placement in the lower harbor CAD cell while maintaining conditions to promote settling and stability. The increase in storage requirements is due to shortening the time available for consolidation. Schedule acceleration is also predicted to decrease the contaminant losses due to the reduction in the exposure of contaminated CAD cell water for losses to occur.

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Figures